

through autumn and winter, if it be mild. With regard to *Trifolium subterraneum*, as it was about thirty years ago when observed it, I cannot now be certain that it was actually cleistogamous; but it grew with just the same habit as the above, and was most probably self-fertile as they are.

GEORGE HENSLOW.

Nose-Blackening as Preventive of Snow-Blindness.

I BEG to send you an extract from a letter just received from my son, of the Indian Geological Survey Department, and who is at present engaged by the Maharajah of Kashmir in exploring and reporting on his sapphire mines. Since it refers to former communication: in NATURE (vol. xxxviii. pp. 7 and 101), upon a subject of interest to travellers, it may be of use.

I may here mention that my son speaks of having found the Eocene Nummulitic limestone in Zanskar at a height of 18,500 feet above the sea. Sir J. D. Hooker tells me that he has previously observed the Nummulites in Tibet, at a height of 18,000 feet.

J. D. LA TOUCHE.

Stokesay, Craven Arms, November 20.

"Some time ago there was a letter in NATURE describing a method of protecting the eyes from sun-glare, when crossing snow, by blackening the nose and cheeks under the eyes. I tried the dodge the other day, when I was crossing the snow-fields and glaciers from Zanskar, and found it very successful. My shikari and some of the other natives were much amused when I produced a piece of charcoal, and proceeded to blacken my face; but they also tried it, and said that it relieved them very much. I do not know how the effect is produced, but it was much the same as when one went off the snow on to a patch of moraine or rocks clear of snow. The blackening seemed to stop the reflected rays in some way. The natives expressed the feeling by saying that it cooled their faces. I found it quite possible to walk over the snow for many miles without glasses, which are a nuisance, especially on rough ground; but without the blackening I had to put them on. The sun at these high altitudes has much greater effect than in England when the ground is covered with snow."

Amber.

IN NATURE (vol. xxvi. p. 63), I find the following note:—"The largest piece of amber ever discovered was recently dug up near the Nobi's Gate, at Altona. It weighed 850 grammes." I beg to state that a piece of amber, weighing 5.6 kilogrammes, is in the possession of Messrs. Stantien and Becker, in Königsberg, and that pieces weighing 6.5 and 9.5 kilogrammes can be seen in the Berlin Mineralogical Museum, both discovered off the sea coast of North Germany. Even as far inland as Silesia, a piece of Baltic amber, weighing 3 kilogrammes, has been found in the bed of the River Oder, near Breslau. Baltic amber occurs in Silesia also as high as 1400 feet above the level of the sea.

A. B. MEYER.

Royal Museum, Dresden, November 19.

ON THE MECHANICAL CONDITIONS OF A SWARM OF METEORITES.¹

II.

THE next point to consider is the mass and size which must be attributed to the meteorites.

The few samples which have been found on the earth prove that no great error can be committed if the average density of a meteorite be taken as a little less than that of iron, and I accordingly suppose their density to be six times that of water.

Undoubtedly in a meteor-swarm all sizes co-exist (a supposition considered hereafter); for even if originally of uniform size they would, by subsequent fracture, be rendered diverse. But in the first consideration of the problem they have been treated as of uniform size; and, as actual sizes are nearly unknown, results are given for meteorites weighing $3\frac{1}{2}$ grammes. From these, the values

for other masses are easily derivable. It is known that meteorites are actually of irregular and angular shapes, but certainly no material error can be incurred when we treat them as being spheres.

The object of all these investigations is to apply the formulæ to a concrete example. The mass of the system is therefore taken as equal to that of the sun, and the limit of the swarm at any arbitrary distance from the present sun's centre. The theory is of course more severely tested the wider the dispersion of the swarm, and accordingly in a numerical example the outside limit of the solar swarm is taken at $44\frac{1}{2}$ times the earth's distance from the sun, or further beyond the planet Neptune than Saturn is from the sun. This assumption makes the limit of the isothermal sphere at a distance 16, about half-way between Saturn and Uranus.

In this case the mean velocity of the meteorites in the isothermal sphere is $5\frac{1}{2}$ kilometres per second, being $\sqrt{\frac{1}{2}}$ of the linear velocity of a planet revolving about a central body with a mass equal to 46 per cent. of that of the sun, at distance 16. In the adiabatic layer it diminishes to zero at distance $44\frac{1}{2}$. This velocity is independent of the size of the meteorites. The mean free path between collisions ranges from 42,000 kilometres at the centre, to 1,300,000 kilometres at radius 16, and to infinity at radius $44\frac{1}{2}$. The mean interval between collisions ranges from a tenth of a day at the centre, to three days at radius 16, and to infinity at radius $44\frac{1}{2}$. The criterion of applicability of hydrodynamics ranges from $\frac{1}{80000}$ at the distance of the asteroids, to $\frac{1}{3600}$ at radius 16, and to infinity at radius $44\frac{1}{2}$.

All these quantities are ten times as great for meteorites of $3\frac{1}{2}$ kilogrammes, and a hundred times as great for meteorites of $3\frac{1}{2}$ tonnes.

From a consideration of the tables in the paper it appears that, with meteorites of $3\frac{1}{2}$ kilogrammes, the collisions are sufficiently frequent even beyond the orbit of Neptune to allow the kinetic theory to be applicable in the sense explained. But if the meteorites weigh $3\frac{1}{2}$ tonnes, the criterion ceases to be very small at about distance 24; and if they weigh 3125 tonnes, it ceases to be very small at about the orbit of Jupiter. It may be concluded then that, as far as frequency of collision is concerned, the hydrodynamical treatment of a swarm of meteorites is justifiable.

Although the numerical results are necessarily affected by the conjectural values of the mass and density of the meteorites, yet it was impossible to arrive at any conclusion whatever as to the validity of the theory without numerical values, and such a discussion as the above was therefore necessary.

I now pass on to consider some results of this view of a swarm of meteorites, and to consider the justifiability of the assumption of an isothermal-adiabatic arrangement of density.

With regard to the uniformity of distribution of kinetic energy in the isothermal sphere, it is important to ask whether or not sufficient time can have elapsed in the history of the system to allow of the equalization by diffusion.

It is shown therefore in the paper that in the case of the numerical example primitive inequalities of kinetic energy would, in a few thousand years, be sensibly equalized over a distance some ten times as great as our distance from the sun. This result, then, goes to show that we are justified in assuming an isothermal sphere as the centre of the swarm. As, however, the swarm contracts, the rate of diffusion diminishes as the inverse $\frac{2}{3}$ power of its linear dimensions, whilst the rate of generation of inequalities of distribution of kinetic energy, through the imperfect elasticity of the meteorites, increases. Hence, in a late stage of the swarm, inequalities of kinetic energy would be set up, there would be a tendency to the production of convective currents, and

¹ Abstract of a Paper read before the Royal Society on November 15 by Prof. G. H. Darwin, F.R.S. Continued from p. 83.

thus the whole swarm would probably settle down to the condition of convective equilibrium throughout.

It may be conjectured, then, that the best hypothesis in the early stages of the swarm is the isothermal-adiabatic arrangement, and later an adiabatic sphere. It has not seemed worth while to discuss this latter hypothesis in detail at present.

The same investigation also gives the coefficient of viscosity of the quasi-gas, and shows that it is so great that the meteor-swarm must, if rotating, revolve nearly without relative motion of its parts, other than the motion of agitation. But as the viscosity diminishes when the swarm contracts, this would probably not be true in the later stages of the history, and the central portion would probably rotate more rapidly than the outside. It forms, however, no part of the scope of this paper to consider the rotation of the system.

The rate of loss of kinetic energy through imperfect elasticity is next considered, and it appears that the rate, estimated per unit time and volume, must vary directly as the square of the quasi-pressure, and inversely as the mean velocity of agitation. Since the kinetic energy lost is taken up in volatilizing solid matter, it follows that the heat generated must follow the same law. The mean temperature of the gases generated in any part of the swarm depends on a great variety of circumstances, but it seems probable that its variation would be according to some law of the same kind. Thus, if the spectroscope enables us to form an idea of the temperature in various parts of a nebula, we shall at the same time obtain some idea of the distribution of density.

It has been assumed that the outer portion of the swarm is in convective equilibrium, and therefore there is a definite limit beyond which it cannot extend. Now a medium can only be said to be in convective equilibrium when it obeys the laws of gases, and the applicability of those laws depends on the frequency of collisions. But at the boundary of the adiabatic layer the velocity of agitation vanishes, and collisions become infinitely rare. These two propositions are mutually destructive of one another, and it is impossible to push the conception of convective equilibrium to its logical conclusion. There must, in fact, be some degree of rarity of density and of collisions at which the statistical treatment of the medium breaks down.

I have sought to obtain some representation of the state of things by supposing that collisions never occur beyond a certain distance from the centre of the swarm.

Then from every point of the surface of the sphere, which limits the region of collisions, a fountain of meteorites is shot out, in all azimuths and at all inclinations to the vertical, and with velocities grouped about a mean according to the law of error. These meteorites ascend to various heights, without collision, and, in falling back on to the limiting sphere, cannonade its surface, so as to counterbalance the hydrostatic pressure at the limiting sphere.

The distribution in space of the meteorites thus shot out is investigated in the paper, and it is found that near the limiting sphere the decrease in density is somewhat more rapid than the decrease corresponding to convective equilibrium.

But at more remote distances the decrease is less rapid, and the density ultimately tends to vary inversely as the square of the distance from the centre.

It is clear that according to this hypothesis the mass of the system is infinite in a mathematical sense; for the existence of meteorites with nearly parabolic and hyperbolic orbits necessitates an infinite number, if the loss of the system shall be made good by the supply.¹

But if we consider the subject from a physical point of

¹ It must also be borne in mind that the very high velocities which occur occasionally in a medium with perfectly elastic molecules, must happen with great rarity amongst meteorites. An impact of such violence that it ought to generate a hyperbolic velocity will probably merely cause fracture.

view, this conclusion appears unobjectionable. The ejection of molecules with exceptionally high velocities from the surface of a liquid is called evaporation, and the absorption of others is called condensation. The general history of a swarm, as sketched at the beginning, may be put in different words, for we may say that at first a swarm gains by condensation, that condensation and evaporation balance, and finally that evaporation gains the day.

If the hypothesis of convective equilibrium be pushed to its logical conclusion, we reach a definite limit to the swarm, whereas if collisions be entirely annulled the density goes on decreasing inversely as the square of the distance. The truth must clearly lie between these two hypotheses. It is thus certain that even the small amount of evaporation shown by the formulæ derived from the hypothesis of no collision must be in excess of the truth; and it may be that there are enough waifs and strays in space ejected from other systems to make good the loss. Whether or not the compensation is perfect, a swarm of meteorites would pursue its evolution without being sensibly affected by a slow evaporation.

Up to this point the meteorites have been considered as of uniform size, but it will be well to examine the more truthful hypothesis that they are of all sizes, grouped about a mean according to a law of error.

It appears, from the investigation in the paper, that the larger stones move slower, the smaller ones faster, and the law is that the mean kinetic energy is the same for all sizes. It is proved that the mean path between collisions is shorter in the proportion of 7 to 11, and the mean frequency of collision greater in the proportion of 4 to 3, than if the meteorites were of uniform mass equal to the mean. Hence the numerical results found for meteorites of uniform size are applicable to non-uniform meteorites of a mean mass about a third greater than the uniform mass; for example, the results for uniform meteorites of $3\frac{1}{2}$ tonnes apply to non-uniform ones of mean mass a little over 4 tonnes.

The means here spoken of refer to all sizes grouped together, but there is a separate mean free path and mean frequency appropriate to each size. These are investigated in the paper, and their values illustrated in a figure. It appears that collisions become infinitely frequent for the infinitely small ones, because of their infinite velocity, and again infinitely frequent for the infinitely large ones, because of their infinite size. There is a minimum frequency of collision for a certain size, a little less in radius than the mean radius, and considerably less in mass than the mean mass.

For infinitely small meteorites the mean free path reaches a finite limit, equal to about four times the grand mean free path; and for infinitely large ones, the mean free path becomes infinitely short. It must be borne in mind that there are infinitely few of the infinitely large and infinitely small meteorites. Variety of size does not then, so far, materially affect the results.

But a difference arises when we come to consider the different parts of the swarm. The larger meteorites, moving with smaller velocities, form a quasi-gas of less elasticity than do the smaller ones. Hence the larger meteorites are more condensed towards the centre than are the smaller ones, or the large ones have a tendency to fall down, whilst the small ones have a tendency to rise. Accordingly, the various kinds are to some extent sorted according to size.

An investigation is made in the paper of the mean mass of meteorites at various distances from the centre, both inside and outside of the isothermal sphere, and a figure illustrates the law of diminution of mean mass.

It is also clear that the loss of the system through evaporation must fall more heavily on the small meteorites than on the large ones.

After the foregoing summary, it will be well to briefly

recapitulate the principal physical conclusions which seem to be legitimately deducible from the whole investigation; in this recapitulation qualifications must necessarily be omitted or stated with great brevity.

When two meteorites are in collision, they are virtually highly elastic, although ordinary elasticity must be nearly inoperative.

A swarm of meteorites is analogous with a gas, and the laws governing gases may be applied to the discussion of its mechanical properties. This is true of the swarm from which the sun was formed, when it extended beyond the orbit of the planet Neptune.

When the swarm was very widely dispersed, the arrangement of density and of velocity of agitation of the meteorites was that of an isothermal-adiabatic sphere. Later in its history, when the swarm had contracted, it was probably throughout in convective equilibrium.

The actual mean velocity of the meteorites is determinable in a swarm of given mass, when expanded to a given extent.

The total energy of agitation in an isothermal-adiabatic sphere is half the potential energy lost in the concentration from a condition of infinite dispersion.

The half of the potential energy lost, which does not reappear as kinetic energy of agitation, is expended in volatilizing solid matter, and heating the gases produced on the impact of meteorites. The heat so generated is gradually lost by radiation.

The amount of heat generated per unit time and volume varies as the square of the quasi-hydrostatic pressure, and inversely as the mean velocity of agitation. The temperature of the gases volatilized probably varies by some law of the same nature.

The path of a meteorite is approximately straight, except when abruptly deflected by a collision with another. This ceases to be true at the outskirts of the swarm, where the collisions have become rare. The meteorites here describe orbits under gravity which are approximately elliptic, parabolic, and hyperbolic.

In this fringe to the swarm the distribution of density ceases to be that of a gas under gravity; and as we recede from the centre the density at first decreases more rapidly, and afterwards less rapidly than if the medium were a gas.

Throughout all the stages of its history there is a sort of evaporation by which the swarm very slowly loses in mass, but this loss is more or less counterbalanced by condensation. In the early stages the gain by condensation outbalances the loss by evaporation; they then equilibrate, and finally the evaporation may be greater than condensation.

Throughout the swarm the various meteorites are to some extent sorted according to size; as we recede from the centre the number of small ones preponderates more and more, and thus the mean mass continually diminishes with increasing distance. The loss by evaporation falls principally on the small meteorites.

A meteor swarm is subject to gaseous viscosity, which is greater the more widely diffused is the swarm. In consequence of this a widely extended swarm, if in rotation, will revolve like a rigid body without relative motion (other than agitation) of its parts.

Later in the history the viscosity will probably not suffice to secure uniformity of rotation, and the central portion will revolve more rapidly than the outside.

The kinetic theory of meteorites may be held to present a fair approximation to the truth in the earlier stages of the evolution of the system. But later, the majority of the meteors will have been absorbed by the central sun and its attendant planets, and amongst the meteors which remain free the relative motion of agitation must have been largely diminished. These free meteorites—the dust and refuse of the system—probably move in clouds, but with so little remaining motion of agitation that

(except perhaps near the perihelion of very eccentric orbits) it would scarcely be permissible to treat the cloud as in any respect possessing the mechanical properties of a gas.

The value of this whole investigation will appear very different to different minds. To some it will stand condemned as altogether too speculative; others may think that it is better to risk error in the chance of winning truth. To me, at least, it appears that this line of thought flows in a true channel; that it may help to give a meaning to the observations of the spectroscopist; and that many interesting problems, here barely alluded to, may perhaps be solved with sufficient completeness to throw light on the evolution of nebulae and planetary systems.

EDISON'S PERFECTED PHONOGRAPH.

THE marvellous results attained by Mr. Edison's recent improvement on, or, more properly perhaps, resurrection of, the original phonograph of 1878 have induced us to present a view of the latest form of the instrument, together with a short description of its main features and most recent performances.

Mr. Edison is still occupied in perfecting the instrument, and scarcely a week passes without his sending over to his European colleague, Colonel Gouraud, substantial evidences of progress towards perfecting the arrangements either for the recording and reproducing of all kinds of sounds, or else in the construction and the postal conveyance of phonograms.

Although, therefore, the instrument can hardly at present be said to have reached its final stage of development, in its chief constructive points it may be regarded as practically perfected; while some recent trials of it show that it is capable not merely of recording, but of reproducing, every kind of sound with which we are acquainted, including articulate speech, with a fidelity little short of absolute perfection.

When Léon Scott invented his phonautograph, he unconsciously came near the phonograph, though he merely contented himself with reproducing the vibrations pictorially on a blackened surface. Prof. Helmholtz, on the other hand, by his profound studies in the analysis and synthesis of speech into fundamentals, accompanied by varying combinations of subsidiary harmonics, seems to have created quite a scare among the phonographists, by showing them what a terribly complicated affair articulate speech was. In the phonograph, however, we have a machine which not only differentiates all these complicated systems of vibrations, checks, and harmonics, but integrates them equally well. It is, moreover, capable of repeating the integrations practically as often as we please.

This perfected power of record, reproduction, and preservation of sound has been accomplished partly through the substitution of a specially prepared wax for the original tinfoil, but also a good deal through other improvements in the diaphragms, needles, &c. The vibrations of the recording diaphragm are transferred by means of a cutting-needle to the wax, which is thus carved and indented into a series of hills and valleys, which represent in *intaglio* the resultant form of the original sound-vibrations, including part, if not all, of the minor inflections due to the presence of the subsidiary harmonics or overtones.

The tinfoil used in the original machine of 1878 only very partially fulfilled the office of a recording surface, and since every indentation in it necessarily involved a corresponding rise of the material on either side, the vibrations of the recording style, and *a fortiori* of the air itself, were only very imperfectly reproduced on its surface. The hollow character of the undulations, moreover, caused them to be easily effaced after a few repetitions.

The records on the wax, on the other hand, have been recently reproduced over 3000 times.